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Impact of rabbits on native bush remnants

T J Lowe, S H Wheeler & L E Twigg

Vertebrate Pest Research Section, Department of Agriculture, Western Australia
100 Bougainvillea Avenue, Forrestfield WA 6058
✉ tlowe@agric.wa.gov.au ✉ ltwigg@agric.wa.gov.au

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Abstract

The value of rabbit-proof fencing in protecting both bush remnants and agricultural production from the impact of rabbits was examined in remnants of coastal heath on two farming properties in southern Western Australia. The short- and longer-term effects of confining wild rabbits within these remnants were studied by excluding rabbits from, or confining them to, experimental sites. In the short-term (*i.e.* within 10-14 months), it was difficult to demonstrate an effect of rabbit grazing except that the percentage cover of sedges and native grasses was clearly reduced in the presence of rabbits. Other negative impacts only become obvious over the longer-term (≥2 years) when the percentage cover of sedges and grasses, and the abundance of seedlings and regenerating plants, were reduced as a result of grazing by rabbits. This effect was more pronounced by year 2, suggesting that the impact of even a small number of rabbits would worsen with time. The impact of rabbits was greatest during periods of peak rabbit abundance.

These findings strongly suggest that any residual rabbits within areas of fenced remnant vegetation must be removed prior to, or immediately after, fencing if the long-term viability of these bush remnants is to be maintained. If this could be achieved, then the use of rabbit-proof fencing to protect small areas of native vegetation from rabbits has some merit, particularly where the remnants have high conservation value.

Key words: rabbit, *Oryctolagus cuniculus*, native bushland, fencing, exclusion

Introduction

European rabbits (*Oryctolagus cuniculus*) have had a devastating impact on both agricultural production and wildlife conservation in Australia (Cochrane & McDonald 1966; Cooke 1981, 1987; Williams *et al.* 1995). Rabbit-proof fencing has been used to varying extents over many years in Australia to protect agricultural enterprises from rabbit damage (Williams *et al.* 1995). However, its use for protecting areas of native vegetation from the detrimental impact of rabbits has received little attention. In Western Australia, areas of native vegetation on farms have been left uncleared, particularly where they are growing on ridges of light sandy soil which would otherwise be subject to wind erosion. This in turn has created a different problem, because such bush remnants provide ideal habitat for rabbits. Rabbits often attain relatively high numbers in these habitats, coming out to feed on, and often severely damaging, adjacent broad-acre crops and pastures. Although their impact on bush remnants in these circumstances is poorly documented, rabbits are believed to have a significant negative impact on this vegetation. Annual poisoning programs have been used to reduce the impact of rabbits on agricultural production in such situations (Williams *et al.* 1995), but this approach does not solve the problem on a long-term basis. Clearing the native vegetation is not an option because of the potential for soil erosion to occur, and also because of the need for conserving the remnant vegetation.

Intuitively, the use of rabbit-proof fencing to reduce the numbers of rabbits in bush remnants has merit. Such fences confine rabbits to areas with less nutritious food, decreasing rabbit productivity, and preventing immigration. Both these factors can result in reduced rabbit abundance within the fenced remnants. However, landcare professionals are often reticent in recommending rabbit-proof fencing because of the potential concern that any residual rabbits may cause an unacceptable level of damage to the bush remnants. This could occur either in the short-term when rabbit numbers may be relatively high immediately following the fence construction, or over the longer-term with continuous grazing by low numbers of rabbits.

This paper addresses some of these issues, and examines whether (1) there were any short-term initial effects of confined rabbits on native bush remnants over the first year after enclosing a remnant with rabbit-proof fencing, and (2) there were any long-term effects on the vegetation (over >2 years) from a relatively low number of rabbits being confined within fenced bush remnants. We also comment on the benefits and costs of the construction of rabbit-proof fences for crop and pasture protection, and for the protection of bush remnants.

Methods

The study was undertaken in coastal mallee heath situated on two farming properties (Parsons' & Tomlinson's) near Boxwood Hill in southern Western Australia. Boxwood Hill is approximately 50 km due west of Bremer Bay. The sites used in the study had not been burnt for at least 12 years, and probably for much longer than this. Climate is typical Mediterranean with an annual average rainfall of 514 mm. Monthly rainfall records were obtained from the closest official Bureau of Meteorology rainfall recording station 009865 at Warra Jarra, AMG reference zone 50, 673303E 6191882N. Warra Jarra is approximately 3.5 km from the Tomlinson's site and 8 km from Parsons'. Annual rainfall during the trial period was 447 mm in 1999, 441 mm in 2000, and 598 mm in 2001.

Short-term effects of rabbits after fence construction

A 10.5 ha (350 x 300 m) patch of native mallee-heath vegetation on Parsons' property was used to determine the short-term effects of confined rabbits on remnant vegetation (Experiment 1). The impact of rabbits on the remnant vegetation was assessed, as described below, within each of thirty 10 x 10 m plots, 15 in each half of the site. The site was then divided into two halves and we surrounded one half with a rabbit-proof fence (Fig 1). At the same time, we also surrounded five of the 10 x 10 m areas (chosen at random) in both the treatment and experimental control areas with rabbit-proof fencing to exclude rabbits. These exclosures were equivalent to removing the effect of rabbits on the vegetation completely and thus enabled comparison with and without the effects of rabbit grazing. The remaining open (*i.e.* subject to 'normal' rabbit grazing) 10 x 10 m plots (10 in each of the fenced and unfenced areas) enabled the comparison to be made between the areas where rabbits were confined and where they had ready access to surrounding pastures and crops (*i.e.* 'rabbits free to move out'). Vegetation assessments, as described below, were repeated at fixed marked positions at two-monthly intervals for the 14 months immediately after the treatment vegetation was fenced.

Because the treatment in the comparison 'rabbits confined' versus 'rabbits free to move out' was the erection of the external rabbit-proof fence, the open plots (vegetation assessment areas) did not provide true replication, and so the experiment was not suitable for strict statistical analysis. However, this experiment was carried out because information about the initial effect of rabbits is critical in the decision making process about the overall effects of the rabbit-proof fencing, and the documentation of the process was valid, even without rigorous statistics. Means (± standard error) for each vegetation parameter were calculated and plotted for each monitoring period.

Long-term effects of rabbits on remnant vegetation

The long-term effects on vegetation of rabbits confined to bush remnants (Experiment 2) was assessed at two sites (*i.e.* patches of native vegetation) situated on the Tomlinson's "Pallinup Park" property. One site ("Site 1"; 11 ha; 550 x 200 m) had been rabbit-proof fenced 4-5 years previously, and the other ("Site 2"; 8.5 ha; 500 x 170 m) had been similarly fenced less than a year previously. Within each of these sites, 10 locations were randomly selected. At each location, an area of visually uniform vegetation was chosen, and in each of these a 10 x 10 m exclosure was constructed (preventing rabbit access) and a 10 x 10 m open plot, where rabbit access was unimpeded, was marked. In all exclosures and open plots, the vegetation was assessed within five 1 m^2 quadrats as described below. Assessments were made before the exclosures were constructed in 1999, and again at the same time of year in 2000 and 2001 once the 10 m x 10 m exclosures had been erected.

In this assessment, the exclosures constituted the treatment, so on each site there were 10 replicates, and the data were analysed by analysis of variance (Zar 1984). The analysis of variance for each measurement compared the grazed and ungrazed plots in 2000 and 2001 using the measurements from 1999 as a covariate. A split plot analysis of variance was used with the year as the sub-treatment. Residual plots were used to check that the assumptions underlying the analysis of variance were valid. Analysis of variance was also used to compare grazed and ungrazed plots in 1999, prior to any treatment effects. These analyses were made using Genstat (v 6, Lawes Agricultural Trust, Rothamsted).

Vegetation Measures

A point quadrat method (36 points; Gilfillan 1999) was used for assessing percentage cover within 10 m x 10 m permanently marked, randomly selected, plots (n = 5-10) within each of the study sites. Each plot contained five permanently marked 1 m^2 quadrats. One quadrat was located near each corner, and the fifth quadrat was situated in the middle, of each 10 m x 10 m plot. Care was taken to avoid edge effects caused by the fence construction and any perching birds. The following vegetation measures were taken for all quadrats: percent cover of small (<0.5 m high) understorey shrubs (SS), percent cover of sedges and grasses (SG), percent cover of other monocotyledonous plants (OM), number of quadrats (n = 5 per plot) in which seedlings or reshoots of rootstocks were visible (SR Quadrats; score, 0 (none present) to 5 (present in all 5 quadrats), and an abundance index of seedlings and reshoots combined as single category (SR Score: 1 = 1-5 seedlings/reshoots, 2 =

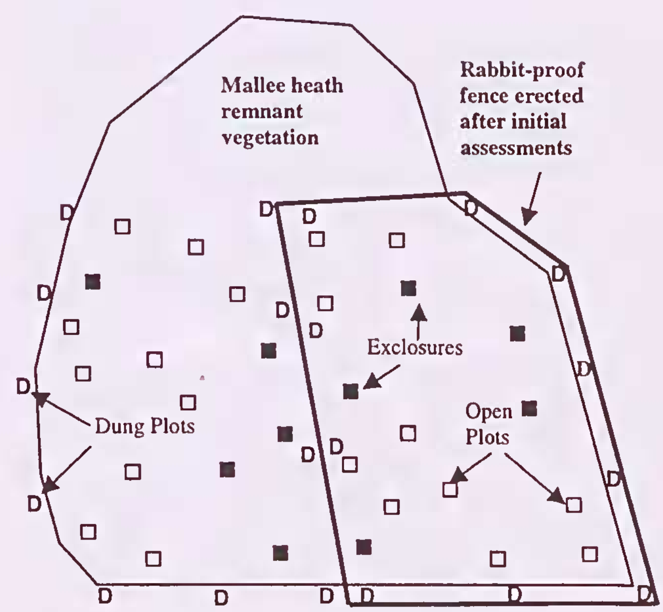

Figure 1. Schematic representation of the experimental design for the short-term study undertaken at the Parsons' site.

6-10, 3 = 11-20, 4 = 21-30, 5 = 31-50, 6 = 51-100, 7 = >100). The height (m) and cover (%) of the dominant (overstorey) shrub layer was also visually estimated for each 10 m x 10 m plot.

Rabbit abundance index (RAI)

Indications of the numbers of rabbits, and changes in rabbit abundance, were obtained as a rabbit abundance index (RAI) by counting rabbit dung on permanently marked quadrats. The dung quadrats were located near each open plot within the fenced and unfenced areas of the remnant vegetation in both experiments. In addition to these, dung quadrats were also positioned around the perimeter of each experimental area (see Fig 1). The number of dung pellets was counted on these quadrats every time that the associated vegetation plots were surveyed. There were 20 dung quadrats in each area of Experiment 1 and 30 quadrats in each area used in Experiment 2. The quadrats comprised 1 m^2 of bare soil (sand), and they were brushed clean after each count.

Benefits and costs of rabbit-proof fencing

To demonstrate the benefits and costs associated with the erection of rabbit-proof fencing to farmers and other landholders, areas of crop lost to rabbits were estimated by physically measuring the area affected on foot and/or by vehicle in areas where rabbits had ready access to paddocks. Production losses were calculated from the paddock yield per hectare and the current price (2001, Australian $) at 'harvest'. The cost of erecting the rabbit-proof fences was also determined.

Results

Short-term effects of rabbits on remnant vegetation

The numbers of rabbits in the fenced and unfenced areas were similar, and low, at the time the fence was constructed (Fig 2). Rabbit numbers in the fenced vegetation, as measured by the RAI, remained low throughout the experiment. However, in the unfenced vegetation there was a considerable rise in the dung counts in November which corresponds with the end of the breeding season when independent sub-adult rabbits are most abundant. The RAI suggests that rabbit numbers outside the fence rose to about five times those within the fenced vegetation. From then until the end of the experiment in July 2001, rabbit density in the unfenced area was always considerably higher than in the fenced vegetation with the confined rabbits (Fig 2).

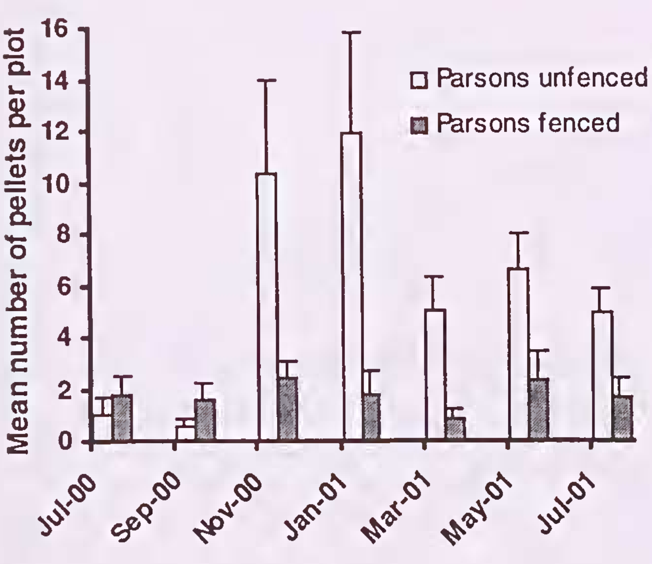

Figure 2. Changes in the rabbit abundance index (mean dung pellets per plot) for the fenced and unfenced areas of remnant vegetation during the investigation of the short-term effects of confined rabbits. Data are mean (± se) of the number of pellets per 1 m^2 quadrat (n = 20).

The overall seasonal pattern in the numbers of seedlings and reshoots (*i.e.* re-sprouting vegetation) observed in the exclosures and open plots at Parsons' site was similar between the fenced and unfenced areas (Fig 3). There was a rise in the abundance of this vegetation class in July, followed by a decline to extremely low levels in summer (January to March), and a sharp rise between May and July following the late break of season. There were, however, some differences in the detail of this response that are worthy of note. The most marked decline in the numbers of seedlings and reshoots occurred in the open plots in the unfenced vegetation between September and November. This corresponds with the considerable rise in rabbit density between the same sampling times (Fig 2). In January, when the numbers of seedlings and reshoots were declining to low levels, the open plots on both the fenced and unfenced areas showed significantly lower numbers of seedlings and reshoots than in the fenced exclosures, where rabbits had no access to the remnant vegetation. It is interesting to note that on the unfenced area, the rise between May and July was similar to the rises in the fenced area, and to that which occurred within the exclosures. This was in spite of the continuing higher levels of rabbit density as indicated by the dung counts (Fig 2). It must be remembered, though, that the rabbits in the unfenced area also had access to annual species growing in the open paddock surrounding the site.

Changes in the percentage vegetation cover of the sedges and grasses vegetation class over time, with and without confined rabbits, were similar throughout the experiment, with one exception (Fig 4). The increase in the amount of sedges and grasses seen between September and November (Spring growth) in the exclosures and in the open plots on the fenced area, was not seen in the open plots on the unfenced remnant vegetation where grazing by rabbits was unrestricted. Interestingly though, the effect on sedges and grasses did not appear to continue through January although the number of rabbits on the unfenced area remained relatively high during this period (Fig 2).

There was also a decline in the percentage cover of sedges and grasses on all open plots and in most exclosures between May and July 2001 (Fig 4). The biggest decline was in the open plots with unrestricted rabbit access within the fenced area. In the previous year, sedges and grasses had been increasing at this time of year. The decrease in the sedge and grass cover between May 2001 and July 2001 possibly reflect the later on-set of autumn rains in 2001 in comparison to 2000.

Changes in the percentage cover of small shrub category had the same seasonal trends as reported above for the other vegetation classes. There was no change in

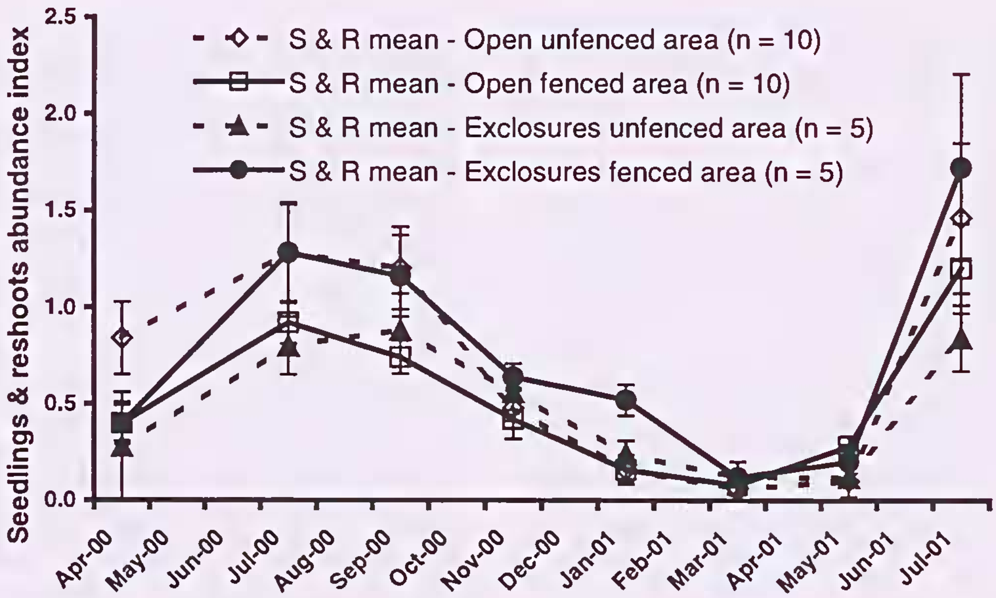

Figure 3. Changes in the abundance index of the seedlings and reshoots category as a result of rabbit grazing within fenced and unfenced areas of remnant vegetation at Parsons' site. An abundance index scale of 1 to 7 was used to score the 5 quadrats within each plot (see methods). Values are mean (± se) of the abundance index scores for the plots in each area.

the tall (over-storey) shrub category during the trial period. Rabbits would not be generally expected to have a severe short-term impact on small and tall shrubs unless rabbit densities were very high.

Long-term effects of rabbits on remnant vegetation

At the start of this experiment in 1999, there were no significant differences in the vegetation parameters measured between the exclosure (ungrazed) and the open (grazed) plots. The resulting *P*-values for the comparison between ungrazed and grazed plots were; shrub height, 0.144; shrub density, 0.206; cover – small shrubs (SS), 0.977; cover – sedges and grasses (SG), 0.917; other monocotyledonous plants (OM), 0.353; seedlings and reshoots – quadrats, 0.154; seedlings and reshoots – score (square root transformation), 0.204. This indicates that the variety and abundance of the plants were similar in these plots before the rabbit-proof fence was erected to exclude rabbits from the exclosure plots.

There were no significant differences in shrub height or density between the ungrazed and grazed plots over the two years of measurement after the erection of the rabbit-proof fences to exclude rabbits from the ungrazed plots. However, there were some interesting differences for many of the other vegetation measurements taken. The ANOVA used was a split plot design with a blocking factor (the two sites, df = 1), and with the corresponding 1999 pre-treatment levels used as a covariate. This approach did not test for differences between sites as the main interest was in the response of the remnant

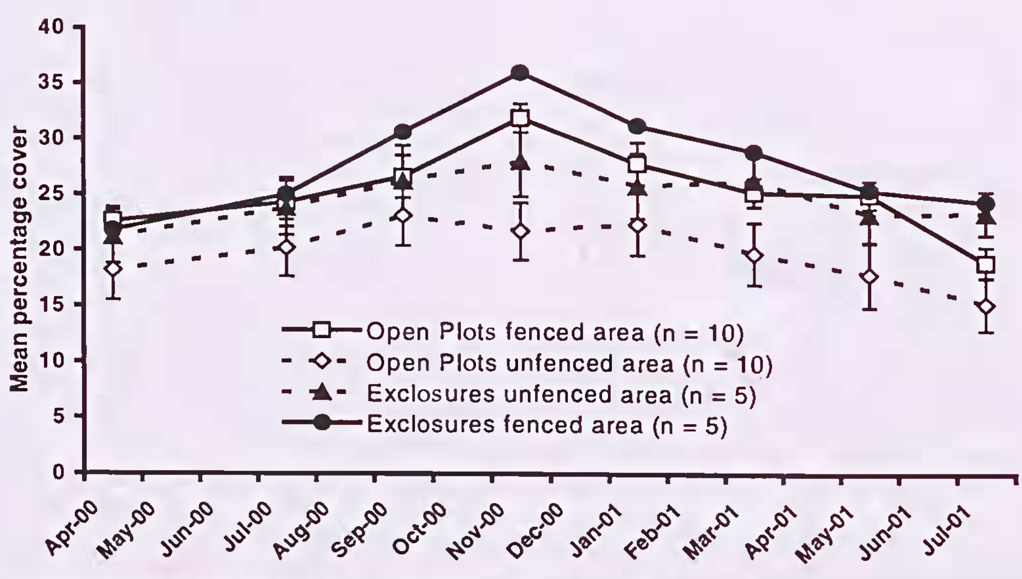

Figure 4. Changes in the percentage cover of the sedges and grasses category as a result of rabbit grazing in the fenced and unfenced areas of remnant vegetation at Parsons' site. The results from rabbit exclosure plots are included for comparison. Values are mean (± se) percentages of these plants in the plots at each area.

Table 1

Analysis (ANOVA) of the differences between the ungrazed (exclosure) and grazed (open) plots over the two year 'experimental' period. SS, small shrub cover; SG, sedge and grass cover; OM, other monocotyledonous plant cover; SR-Quadrats, number of quadrats with visible seedlings or reshooting rootstocks; SR-Score, seedlings and reshoots score without square root transformation. Significant P values are in bold.

	Probability			Treatment means			Year means		
Category	Treatment	Year	Treatment x Year	Exclosure	Open	5% LSD critical values[A]	2000	2001	5% LSD critical values[A]
SS	0.460	**0.035**	0.802	0.177	0.184	0.021	0.189	0.173	0.015
SG	**<0.001**	**<0.001**	0.094	0.428	0.354	0.024	0.435	0.346	0.019
OM	0.811	0.440	0.699	0.009	0.008	0.006	0.008	0.009	0.003
SR Quadrats	0.060	**0.004**	0.468	3.55	3.03	0.541	2.93	3.65	0.484
SR Score (No transform)	**<0.001**	**<0.001**	0.507	6.05	4.35	0.726	4.45	5.95	0.755

[A] The difference between each 'pair' of means for each parameter needs to be greater than the 5% LSD value to be significant at the 5% level.

vegetation with and without rabbit grazing (*i.e.* the treatment). However, the analyses did remove any differences between sites (block stratum), and between the 20 locations (plots) at each individual site (block.pair stratum) before examining the effects of treatment (ungrazed *vs* grazed) and year (2000 *vs* 2001). The covariate (*i.e.* the 1999 pre-treatment levels) was significant ($P < 0.05$) for all of the plant parameters tested. This indicates that the response of the vegetation in 2000 and 2001 was related to the amount and species diversity of the remnant vegetation at the start of the experiment in 1999. Thus, the use of the covariate 'compensates' for this relationship so that only the treatment effects are compared (Zar 1984).

Rabbit grazing had a significant impact upon the sedges and grasses, and on the abundance of seedlings and reshoots (treatment effect; Table 1). This effect was also greater in Year 2 as the year effect was significant for these two vegetation parameters (Table 1). However, although the magnitude of this change varied between years, the overall trends were the same in both years as none of the interactive terms (treatment x year) were significant (Table 1).

Changes in rabbit abundance throughout the long-term trial, as indicated by the RAI, are given in Fig 5. Rabbit numbers on Site 2, the area that had been fenced approximately 1 year prior to the experiment, were moderate and generally constant throughout apart from the higher numbers during the breeding season (spring/November). In contrast, rabbit numbers were lower on Site 1, the area that had been fenced for approximately 4-5 years. Although rabbit numbers were similar between the two sites at the commencement of the trials, the seasonal breeding peak in numbers, as determined by the RAI, was almost absent on Site 1 in subsequent years (Fig 5).

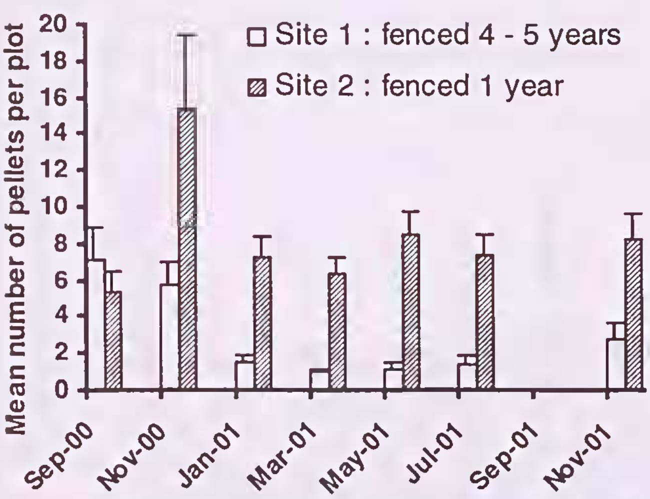

Figure 5. Changes in the rabbit abundance index (mean dung pellets per plot) for the fenced and unfenced areas of remnant vegetation during the investigation of the longer-term effects of rabbits being confined within this vegetation. Values are mean (± se) of the number of pellets per 1 m² quadrat (n = 30). Sites 1 and 2 had been fenced for approximately 4-5 years and 1 year respectively, prior to the experimental plots being established (*i.e.* when the twenty 10 m x 10 m exclosures were fenced).

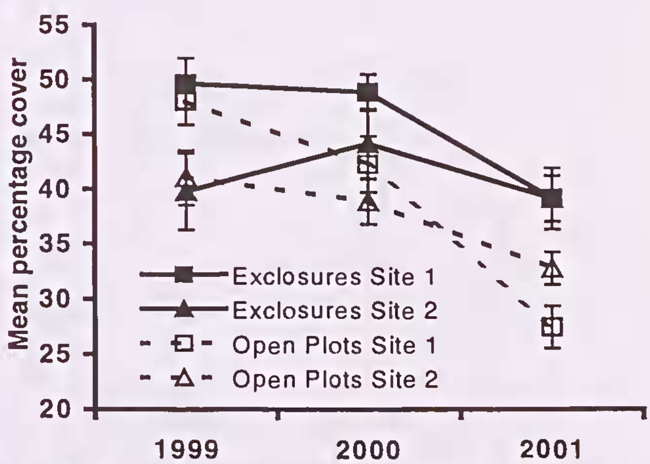

Figure 6. Changes in the percentage cover of the sedges and grasses category as a result of rabbit grazing in the fenced and unfenced areas of remnant vegetation at Tomlinson's site. Results from rabbit exclosure plots are included for comparison. Values are mean (± se) percentage cover of these plants in the 10 plots at each site. Sites 1 and 2 had been fenced for approximately 4-5 years and 1 year, respectively prior to the experimental plots being established.

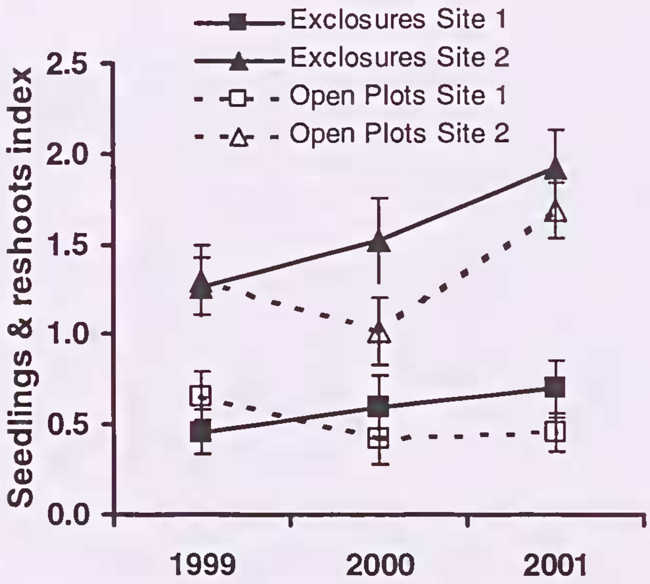

Figure 7. Changes in the abundance index for the seedlings and reshoots category as a result of rabbit grazing in the fenced and unfenced areas of remnant vegetation at Tomlinson's site. The results from rabbit exclosure plots are included for comparison. An abundance index scale of 1 to 7 was used to score the 5 quadrats within each plot (see methods). Values are mean (± se) of the abundance index scores for the plots (n = 10) at each site. Sites 1 and 2 had been fenced for approximately 4-5 years and 1 year respectively, prior to the experimental plots being established.

The main effects of rabbit grazing on remnant vegetation when rabbits were confined within this vegetation are shown in Figs 6 and 7. The ANOVA (Table 1) showed that both rabbit grazing and time (*i.e.* years) had a significant effect on the percentage vegetation cover for sedges and grasses (Fig 6). Although the abundance of sedges and grasses in the open plots and exclosures on each site were similar when the experiments were commenced in 1999, there was a consistent divergence over time between the ungrazed and grazed plots on both sites. This was presumably due to the cumulative effects of rabbit grazing, as percentage cover on the open plots was markedly reduced compared with the amount of vegetation within the ungrazed exclosures. This effect appeared to become more pronounced over time as there was a clear difference between years (Table 1). However, initially, there was little overall change in the percentage cover of sedges and grasses between 1999 and 2000, but there was a marked decline in this vegetation parameter between 2000 and 2001. This change may well have been 'driven', at least partially, by rainfall events. The period between November 2000 and November 2001 had much less rain than the corresponding period in 1999-2000 (Fig 8). In fact, rainfall over the 10 months between September 2000 and June 2001 was also considerably less than the long-term average for this period.

The seedling and reshoots score (= abundance index), and the number of quadrats with seedlings and re-shooting rootstocks, also showed a significant effect of both year and exposure to rabbit grazing at both sites (Table 1; Fig 7). Like sedges and grasses, changes in these parameters almost certainly reflected recent preceding rainfall (Fig 8). However, in the absence of grazing by rabbits (*i.e.* in the exclosure plots; Fig 7) there was an increase in the percentage cover of the seedlings and reshoots from year to year. Grazing by rabbits diminished the numbers of seedlings and reshoots, with the biggest effect occurring in November 2000 after two months of very low rainfall. As indicated by the RAI, this period also corresponds with the observed peak in rabbit abundance (Fig 5). The impact of rabbit grazing is also clearly illustrated in Fig 9 which shows the effect of even low numbers of rabbits within the fenced bush remnant (~ 5 ha^{-1}) compared to the surrounding pasture with no/ few rabbits.

Costs of rabbit-proof fencing

Although the overall area of crops and pasture that was affected by rabbit grazing in the absence of rabbit-proof fencing was often small, there was usually a total loss of plant biomass in the affected areas. In canola crops, these losses ranged from $288 to $1296 (mean $972,

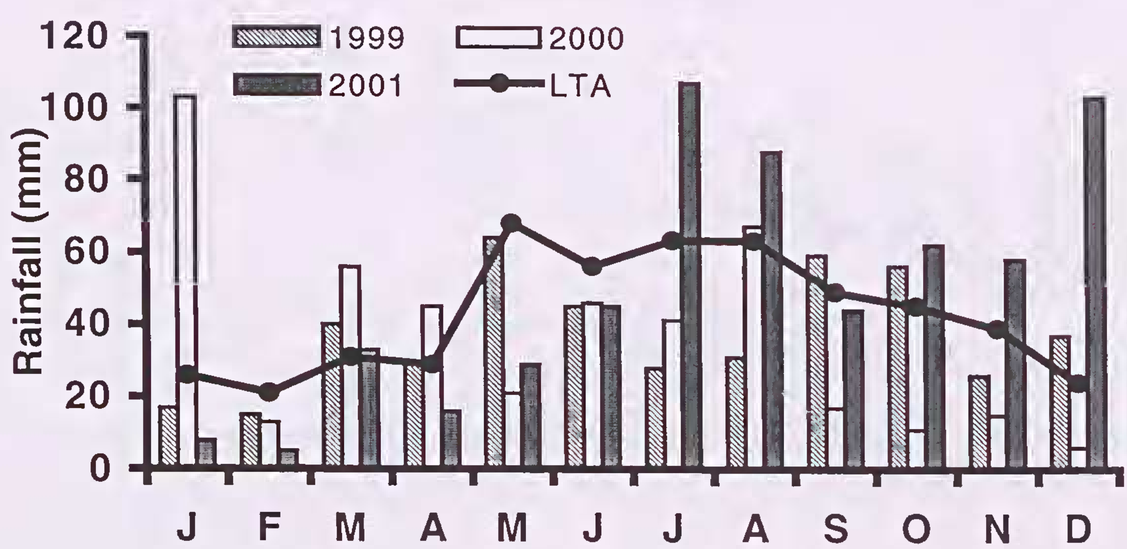

Figure 8. Long-term average (LTA) rainfall (mm), and rainfall (mm) for each of the years during the short- and long-term studies at Boxwood Hill. The recording station was within 8 km of the study sites.

Figure 9. The clear 'rabbit-graze line' within the bush remnant (with rabbits) behind the rabbit-proof fence compared to the lack of impact in the surrounding pasture with no rabbits.

n = 4) with 0.5 ha to 3 ha (mean 1.75 ha) of crop lost. Losses were lower in lupin crops during the study, and ranged from $50 to $297 (mean $195, n = 3) or 0.25 ha to 1.5 ha (mean 0.98 ha) of affected crop. Obviously, rabbit-proof fencing is relatively permanent, and if properly maintained is likely to last for at least 15 years. Thus the associated costs would need to be discounted against the benefits obtained over such a time period. There are also tax benefits (*e.g.* depreciation) to landholders. The fence cost approximately $5 000 per km (materials, $4 000; labour, $1 000), and there is also a small on-going maintenance cost. Depending upon the shape and size of the area protected, the use of rabbit-proof fencing would cost between $250 and $500 per hectare of protected 'crop' in the first year (2001 $AUD). However, this outlay would be discounted in subsequent years.

Discussion

Short-term effects of confining rabbits

The abundance of rabbits within the fenced vegetation was always considerably less than that which occurred within the unfenced bush remnant. The dung counts in November 2000 (end of breeding season), for example, indicated a relatively large increase in rabbit numbers in the unfenced remnant vegetation which was not seen in the fenced remnant. This suggests that the rabbits within the fenced vegetation only had access to less palatable/nutritious native vegetation and this may have restricted their reproductive output. Conversely, rabbits in the unfenced remnant vegetation had ready access to a canola crop of higher nutritional value potentially enhancing their reproductive output. Significant breeding by rabbits depends on the provision of green feed of adequate nutritional quality (King & Wheeler 1985; Williams *et al.* 1995; Twigg *et al.* 1998). In the unfenced remnant vegetation, where the increase in rabbit numbers occurred, there seemed to be a greater decline in the abundance of seedlings and reshoots (re-sprouting vegetation). This was accompanied by a decline in the percentage cover of sedges and grasses that was in contrast to the fenced area, where the percentage cover of sedges and grasses had increased.

The number of seedlings and reshoots was similar between the open (grazed) and exclosure (ungrazed) plots within fenced and unfenced remnant vegetation after the 14-month monitoring period (Fig 3). There are four possible causes for this similarity, and these are not necessarily mutually exclusive. Firstly, rabbit numbers within the fenced vegetation were low and may have been below the threshold level required to cause obvious environmental damage. Conversely, because the rabbits in the unfenced remnant vegetation had ready access to other foods (eg crops and pasture), there may not have been a great demand for these rabbits to feed within the remnant vegetation as they always had access to an adequate food supply within the surrounding paddocks. Hence their impact on the remnant vegetation was minimal. This may occur irrespective of rabbit density. Thirdly, the seed bank/species richness of the remnant vegetation was depauperate, and hence the vegetation was unable to respond. We do not favour this option as our study sites had a diverse range of plant species, and we did observe a difference in the response between the exclosures and the open plots in the long-term experiment. Finally, because the numbers of rabbits ultimately confined within the fenced remnant vegetation were relatively low, it could take several years before any detrimental impacts become obvious. We believe the latter is an important consideration and that the fencing of remnant vegetation should include a strategy (*e.g.* 1080-baiting; see Williams *et al.* 1995) to reduce rabbit numbers prior to totally enclosing a bush remnant.

The short-term response of remnant vegetation following the rabbit-proof fencing appeared to be mixed. The positives mainly resulted from keeping rabbits out, which helped to maintain the confined rabbit population at low levels. However, there did appear to be some deleterious effects due to the confinement of rabbits, such as a decrease in the percentage cover of sedges and grasses.

Longer term effects of confining rabbits

Although there was a significant effect between years (the two years were markedly different in rainfall during the growing season), there is no doubt that low numbers of confined rabbits (*e.g.* ~ 5 ha^{-1}) had a significant impact on fenced remnant vegetation. In particular, the abundance of seedlings and reshoots was reduced, and sedge and grass cover was diminished, relative to the exclosures in the corresponding 1-year and 5 to 6-year fenced remnant vegetation. Given that this effect occurred within 3-7 years from when the fences were originally erected (*e.g.* for 1 year plus 2 years of experimentation), then the long-term implication is that a substantial change in the biomass and composition of bush remnants is a likely consequence of confining even low numbers of rabbits within these remnants. It is possible that some of the deleterious effects of rabbit grazing may be exacerbated by environmental stress. That is, such effects may not become obvious until the fenced remnant vegetation undergoes an additional source of abiotic stress, such as below average rainfall.

It is also noteworthy that our findings are consistent with those of other studies, and some examples of this are presented below.

- Rabbits will often selectively browse seedlings of certain shrubs and trees. In fact, there may be no 'safe' rabbit density for some tree and shrub seedlings (Morris 1939; Lange & Graham 1983). For example, with free-ranging, unconfined populations, even rabbit densities of around 4 ha^{-1} can prevent the regeneration/replacement of some plant species, particularly in arid Australia, and this can lead to significant soil erosion (Cooke 1981, 1987; Foran *et al.* 1985).
- Rabbit-grazing can also impact on native grasses, and when rabbits are excluded, native perennial grasses will regenerate and rapidly replace many of the introduced annual grass species (Mallet & Cooke 1986).
- In some sub-alpine areas, the effects of rabbit-grazing resulted in the loss of nine palatable forbs within seven years. However, where rabbits were excluded there was a net overall gain of two species (Leigh *et al.* 1987). The presence of rabbits led to a substantial reduction in the cover, biomass and species diversity of the forbs in this habitat.
- In the Victorian mallee district, seventeen native species of ground-layer plants were recorded where rabbits had been excluded for two years but none of these plant species were found where rabbits had ready access to such areas (Cochrane & McDonald 1966).

These findings, and the results of our study, strongly support the need for a strategy for reducing the numbers of rabbits present in bush remnants prior to the remnant vegetation being totally enclosed with rabbit-proof fencing. This could be achieved by a well conducted baiting program, preferably with 1080, which may or may not need to be integrated with a shooting program to mop up any remaining rabbits. Unless rabbits are eradicated from fenced bush remnants, there will be an ongoing need to conduct regular control programs to prevent/reduce the detrimental effects of rabbit grazing.

Benefits and costs of rabbit-proof fencing

Fencing that excludes rabbits from 'prime habitat' can decrease the effects of rabbit grazing by limiting their capacity for population growth. If conducted on a sufficient scale, then this in turn reduces the number of rabbits that can potentially inflict damage to the surrounding crops and pastures. The benefits of rabbit-proof fencing can outweigh the expenditure and become cost-neutral to agricultural producers in the medium term (⩾2 years). The protection gained is also long-term. With a high value crop such as canola, costs can be recovered within two seasons, depending on the amount of fencing required, and the crop yields and returns obtained. The benefit-to-cost ratio of rabbit-proof fencing to eliminate rabbit damage is likely to be even more favourable for high return horticultural crops/market garden enterprises. This is particularly so as a poisoning program does not provide the same absolute protection compared to that achieved with rabbit-proof fencing. Small crop losses may well continue to occur following a baiting program unless some technique is used to remove any remaining rabbits (*e.g.* shooting).

Implications for rabbit management and bush remnants

Provided that some means are used to reduce residual rabbits, then rabbit-proof fencing of remnant vegetation of high conservation value would be well worthwhile. Obviously the benefits and costs depend on the size of the area that needs to be protected. Nevertheless, we do have some caveats. In the short term (one year), the effect of confining rabbits within remnant vegetation, thereby reducing available rabbit habitat, may be both positive and negative. Such effects were not always easy to define. However, based on the results of our longer term experiment, the effect of confining rabbits within bush remnants over a much longer term (say, 15 years) will almost certainly be negative unless steps are taken to remove the residual rabbits completely (*i.e.* eradication is achieved). This would be quite achievable using a combination of poison baiting and shooting, particularly if control efforts were undertaken when other food is in relative short supply (*e.g.* during summer). If the long-term viability of the remnant bush is to be maintained, then every effort needs to be made to ensure that residual rabbits are completely eradicated. If this is not achieved, then the bush remnants themselves may need to be subjected to regular poisoning campaigns, in addition to the cost of the fence, to prevent the deleterious effects caused by residual rabbits. Such a situation may well be little better (or possibly worse) than employing a regular poisoning program, without the fence, to reduce the impacts of rabbits.

One potential negative impact of using rabbit-proof fencing to protect bush remnants is that it may interfere with the movement of native animals, particularly kangaroos and wallabies. The conservation issues potentially associated with this may be important if species of high conservation value, or species that are under threat, are involved. How important this is may need to be balanced against the losses inflicted to crops and pasture, the potential loss of native vegetation, and the conservation value of the vegetation of concern. Such issues will need to be considered carefully on a case by case basis.

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